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Recent DOD policies removed restrictions from females being assigned to fighter aircraft, in which aircrew are exposed to high $+G_Z$. The objective of the Armstrong Laboratory (AL), Crew Technology Division's Female Acceleration Tolerance Enhancement (FATE) Program was to ensure that G-protective equipment, originally designed for males, would provide female fighter aircrew with optimum acceleration protection. Five major efforts were accomplished: 1) A centrifuge study compared male/female acceleration tolerance/endurance using a +5 to $+9G_Z$ Simulated Aerial Combat Maneuver (SACM) acceleration profile, from which investigators evaluated a gender-specific modification of the standard anti-G suit (CSU-13B/P). Results revealed that males were able to perform the SACM significantly ($p<0.05$) longer (169.4 ± 19.1 s) than could the females (101.4 ± 20.1 s) when the modified suit was not used. When the females performed the SACM in the modified suit, they exhibited SACM endurance (202.4 ± 20.1s) equal to ($P>0.05$) that of the males (169.4 ± 19.1 s). 2) The anti-G suit modification was centrifuge-tested by two female fighter pilots, field tested, and incorporated as a Technical Order Safety Supplement, now available for local squadron use by operational aircrew. 3) An anthropometry study of the potential female aircrew population indicated that an additional size (extra-small, short) CSU-13B/P was needed. 4) Three prototypes of the extra-small, short suit were fabricated and centrifuge-tested, and drawings were provided. 5) A fit evaluation of 10 subjects wearing the COMBined Advanced Technology Enhanced Design G-Ensemble (COMBAT EDGE) pressure vest and the Advanced Technology Anti-G Suit (ATAGS) indicated that the vest, as designed, will effectively fit over 80% of the female population. By fabricating an additional smaller (size 0) ATAGS, we were able to fit 5'1" female subjects.

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TITLE: Female Acceleration Tolerance Enhancement

TABLE OF CONTENTS

FEMALE ACCELERATION TOLERANCE ENHANCEMENT (FATE) Project

INTRODUCTION

Two major policy decisions dramatically impacted requirements to accommodate women into combat aircraft. On 28 April 1993, the Secretary of Defense directed the services to open assignments in combat aircraft to women. This decision greatly expanded the number and types of aircraft that women could fly. Prior to this decision, female pilots and other female aircrew were restricted by directive to aircraft that did not directly engage in combat. The second significant decision impacting the woman pilot was a requirement that the new joint services aircraft for pilot training, the Joint Primary Aircraft Training System (JPATS), be designed to accommodate 80% of US women (1). These size requirements were also adopted for the F-22 Advanced Tactical Fighter.

Current military combat, trainer, and support type aircraft are generally designed to accommodate pilots who are 64 to 77 inches in stature with a sitting height of 34 to 40 inches. When applied to the aircraft cockpit, ejection seat and crew-mounted life support equipment, this design criteria allows approximately 90% of US males to meet size requirements, while only 40% of US females are tall enough to meet the requirements (3,9). The expansion to the size envelope to accommodate 80% of US females will significantly increase the number of women who qualify for flying training. These two decisions--allowing women to fly combat aircraft and greatly increasing the aircrew size and stature ranges that the aircraft will need to accommodate--present a unique challenge to aircraft and life support equipment development, particularly the development of G-protective equipment and evaluations of female acceleration tolerances.

In the 1970s, research to assess the female response to acceleration has been primarily associated with low $+G_Z$ centrifugation (i.e., $\leq +3G_z$) (18,21). In 1986, Gillingham et al. (12) used higher $+G_Z$ levels and reported no significant difference between males and females in either relaxed or straining $+G_z$-tolerance during a standard medical evaluation $+G_Z$ profile ($+8\ G_z$). However, when Gillingham matched the genders for body stature, the mean $+G_Z$-tolerances of the females were significantly lower than the males. This study offers no information with regards to female tolerance to a more operational, performance or endurance-based $+G_Z$ profile such as the simulated air combat maneuver (SACM) (6). Fischer et al. (11), in a retrospective analysis, examined male and female tolerance to high $+G_Z$ in a group of relatively untrained (with regards to performance at high $+G_Z$) subjects. These investigators found that males exhibited a greater ($p \leq 0.05$) tolerance to $+8.0\ G_Z$ than the female subjects, with all subjects employing the anti-G straining maneuver and wearing a standard (CSU-13B/P) anti-G suit. This study also provided no information with regards to female $+G_Z$ tolerance during a more operational, performance or endurance-based $+G_Z$ profile. Additionally, Fischer et al. theorized a more effective straining maneuver in the males due to greater muscular strength and/or anti-G suit misfit in the females as possible reasons for this gender difference and encouraged further research.

G-protective life support equipment includes anti-G suits and assisted positive-pressure breathing systems. Anti-G suits apply pressure to the lower body to ensure adequate blood return to the heart, and assisted positive-pressure breathing systems utilize a torso counter-pressure garment and oral-nasal mask to increase arterial pressure to help compensate for the effects of acceleration in which perfusion pressure to the brain is diminished. The effectiveness of this equipment is largely dependent on the adequacy of its design and fit. Thus, the objective of this research effort was to develop and test modifications or new sizes for both operational and developmental G-protective equipment. To achieve this objective, the following related research and development efforts were conducted. 1) A centrifuge study was conducted to evaluate the effectiveness of gender-oriented alterations to the currently operational standard USAF anti-G suit (CSU-13B/P) and to compare the G-tolerance/endurance of males and females during Simulated Aerial Combat Maneuver (SACM) centrifuge profiles. As a part of the male/female acceleration tolerance comparison, a battery of fitness evaluation procedures also were conducted. 2) A new size for the CSU-13B/P anti-G suit accommodating smaller aircrew was developed, and prototype units were fabricated and tested. 3) Fit trials were conducted to determine requirements and, if necessary, to develop new sizes and alteration procedures, for the COMBined

Advanced Technology Enhanced Design G-Ensemble (COMBAT EDGE) CSU-17/P pressure vest and the Advanced Technology Anti-G Suit (ATAGS).

METHODS AND MATERIALS

G-Protection Equipment

CSU-13B/P Anti-G Suit. The CSU-13B/P is a trouser-like garment which applies both direct (bladder) and indirect (fabric tension) pressure to the lower body via five interconnected air bladders located on each thigh and lower leg and the abdomen. A survey conducted in 1993 provided information about the fit and performance of the CSU-13B/P anti-G suit (20). Sixty-two Air Force pilots and student pilots (34 males and 28 females) who were currently flying or had flown aircraft requiring the use of an anti-G suit, were surveyed. Fifty percent of the female pilots and 24 percent of the male pilots reported that the waist of their CSU-13B/P anti-G suit was too loose. The USAF technical order (T.O. 14P3-6-121) for the standard CSU-13B/P anti-G-suit was designed according to the male body structure. However, females differed significantly from males with respect to body proportionality adjusted for body mass and stature. It has been observed that this Original T.O. suit (OTO suit) did not provide adequate fit for a large number of female aircrew. The USAF technical manual authorized circumferential modifications for the suit; however, the technical manual modifications improved the fit only 7% of the female and 5% of the male pilots. Heaps, et al. (13) conducted a centrifuge evaluation of menstrual cycle effects on acceleration tolerance. As a part of this study, female subjects were exposed to a Simulated Aerial Combat Maneuver (SACM) centrifuge profile in which the subjects were exposed repetitively to +4.5 G_Z and +7.0 G_Z (15 s at each G level). Results indicated that the suit was generally too large in the waist and, when the females were seated in an ejection seat, the suit abdominal bladder tended to ride up over the lower ribs. When the suit was worn in this manner, the inflation of the abdominal bladder caused severe discomfort as the bladder compressed the lower ribcage. Additionally, compression of the diaphragm prevented the proper performance of the anti-G straining maneuver. This finding that the anti-G suit abdominal bladder could cause abdominal discomfort and breathing restriction was not totally unique to females. This problem was identified in a number of acceleration research efforts dating back to World War II (17).

In response to this problem, the Flight Motion Effects Branch (CFTF) of the Armstrong Laboratory (AL) proposed a series of modifications to the OTO suit, based on the specific anthropometric measurements (e.g., waist, hip circumference) believed to be critical in obtaining a optimum anti-G suit fit. The AL modified (AL Mod) suit assured that all aircrew would be wearing what was termed a "best-fit suit," regardless of gender. In 1995, the USAF Life Support program Office published a Safety Supplement to T.O. 14P3-6-121 implementing the AL modifications to the CSU-13B/P anti-G suit, when necessary, to ensure that all aircrew received a best-fit suit. In addition to the CSU-13B/P alterations that were developed as a part of the SACM study, an extra-small, short, CSU-13B/P was developed to accommodate females shorter than 162.6 cm (64 in).

The development of a CSU-13B/P anti-G suit specifically sized to accommodate smaller female aircrew involved a two phase effort. In the first phase, a sizing scheme for CSU-13B/P anti-G suits was established. Proposed changes to aircrew size and stature requirements generated by the Joint Primary Aircraft Training System (JPATS) and F-22 (Advanced Tactical Fighter) programs will require that new anti-G suit sizes be developed to accommodate smaller aircrew. The JPATS aircraft design is expected to allow accommodation of a pilot approximately 62 in. tall weighing 116 lb. The F-22 Advanced Tactical Fighter will also be designed to accommodate the smaller aircrew. Currently, the smallest CSU-13B/P anti-G suit is designed to fit an individual 64 in. tall weighing approximately 130 lb. To support the development of a suit-sizing scheme for small aircrew, a sizing study was conducted by the Armstrong Laboratory, Human Engineering Division at Wright Patterson AFB, OH (DWHRP Annual Report, 29 Aug 1995). This study proposed that three additional anti-G suit sizes be developed to accommodate the smaller aircrew; however, the successful development of modification/alteration procedures for the CSU-13B/P anti-G suit per T.O. 14P3-6-121 allowed adjustments to be made for a wide range in waist, hip and leg circumferences and greatly simplified the sizing issue. The approach used to develop CSU-13B/P anti-G suits for small female aircrew was to use existing anthropometric data to establish a single

additional suit size that would accommodate the required female pilot population. This sizing study was followed by the fabrication and evaluation of prototype CSU-13B/P anti-G suits and the preparation of appropriate patterns and specifications which allowed rapid transition to a production program.

CSU-17/P Pressure Vest. The CSU-17/P pressure vest is a component of the COMBined Advanced Technology Advanced Design G Ensemble (COMBAT EDGE). The CSU-17/P component of this system, assisting positive-pressure breathing during G (PBG) protection, applies direct pressure to the chest via an air bladder which covers the chest and shoulder areas. The vest and oral-nasal mask are pressurized relative to the G-level. Pressurization is started at $+4G_Z$ and increases at 12 mmHg/G to a maximum pressure of 60 mmHG at $+9G_Z$. With retrofit initiated in 1991, the COMBAT EDGE system was fully fielded in USAF F-16s and the F-15E by 1994/5, and is currently being retrofitted into the F-15C/D. Because the COMBAT EDGE system was developed and tested prior to the inclusion of females in the fighter force, fit and performance studies of the CSU-17/P vest with female subjects were not conducted. Female students in USAF School of Aerospace Medicine's Aerospace Medicine Primary Course (for flight surgeons) and Aerospace Physiology Officers courses have worn the COMBAT EDGE system during G-training on the Armstrong Laboratory's human centrifuge. Observations from this training indicated that the CSU-17/P vest tended to be too large in the upper chest and shoulder areas and when pressurized, the vest ballooned in the mid-scapular region. As a part of the Female Acceleration Tolerance Enhancement (FATE) effort, a fit trial was conducted, and procedures were developed to alter the pressure vest to improve the fit for female centrifuge subjects.

ATAGS. ATAGS is a full coverage anti-G suit that provides direct pressure to the full length of the leg via a circumferential bladder. ATAGS includes a relatively small abdominal bladder which applies pressure to the lower abdomen. By tensioning the rear panel of the suit, the abdominal bladder also applies indirect pressure to a portion of the buttocks. Both centrifuge studies and flight demonstrations of the ATAGS have been conducted with male centrifuge subjects and pilots. Two female centrifuge subjects have been exposed to very high-G levels ($+12G_Z$) as a part of an ongoing protocol to evaluate the upper limits of human G-tolerances in advanced technology G-protective ensembles. Observations from these studies indicate that ATAGS fit the female subjects better than did the CSU-13B/P. The lower fitting ATAGS abdominal bladder did not interfere with the subjects respiration or performance of the anti-G straining maneuver; however, to accommodate for female subjects' smaller waists, a reduction of waist circumference may be required.

METHODS: EVALUATION OF CSU-13B/P G-SUIT FIT AND COMPARISON OF MALE/FEMALE TOLERANCE/ENDURANCE

Facilities: All data was collected at the centrifuge facility and Applied Exercise and Work Physiology Laboratory, Crew Technology Division, Armstrong Laboratory, Brooks AFB, TX.

Protocol: The experimental procedures were approved for use on human subjects by the Armstrong Laboratory Institutional Review Board-South (Brooks AFB, TX). All subjects gave informed consent to testing prior to participation in the present study.

Subjects: Thirteen (8 males, 5 females) members of the Brooks AFB Acceleration Research Subject Panel volunteered for participation in this investigation. Subject characteristics are detailed in Table I. All subjects were volunteers and all passed a physical exam similar to the USAF Class III flying physical. The voluntary informed consent of all subjects per Air Force Instruction 40-402 was obtained. The research protocol was reviewed by the Armstrong Laboratory Advisory Committee for Human Experimentation and approved by the USAF Surgeon General. The female subjects were required to use an effective method of birth control for the duration of the study and underwent a urine pregnancy test prior to each centrifuge exposure.

[Table I Here]

Anti-G Suit Fitting: Prior to centrifuge training, male subjects were fitted with the CSU-13B/P anti-G suit (OTO suit) which, for all males, was their best-fit suit. The females were likewise fitted with the OTO suit and were also fitted with the AL Mod suit. As expected, the AL Mod suit was the best-fit suit for all females.

Acceleration Training: Subjects reported for their training sessions in standard flight suit and boots. Electrodes were applied to the subjects for electrocardiographic monitoring during the centrifuge exposures. Over their flight suits, the male subjects wore their OTO suit during training sessions. The female subjects, who had two different anti-G suits (OTO, AL Mod), switched suits on alternating training days. Every effort was made to avoid prejudicing the female subjects concerning differences in configuration of the OTO and AL Mod suit. Since most subjects were experienced centrifuge riders, training sessions usually consisted of one or two rapid-onset rate (+6.0 $G_Z{\cdot}s^{-1}$) exposures to +9.0 G_z for 15 s then performance of the +5.0 to +9.0 G_Z SACM. One cycle of the +5.0 to +9.0 G_Z SACM consists of performing at +5 G_Z for 10 s then increasing to +9 G_Z for 10 s (Figure 1). These cycles are usually repeated until a predetermined endpoint, fatigue or some other endpoint (described later). Most subjects performed a low intensity SACM run (i.e., 2 cycles) before performing a "maximal SACM run" (i.e., repeated SACM cycles until fatigue or other endpoint). Training continued for the subjects until their maximal endurance of the +5.0 to +9.0 G_Z SACM reached a plateau. That is, in order to reduce the chances of a learning or training effect on SACM endurance during the data collection period, subjects were trained until it appeared that minimal improvement in SACM endurance was being made from training session to training session.

[Insert Figure 1]

Acceleration Data Collection: The acceleration data collection profile consisted of: 1) a gradual-onset (+0.1 $G_Z{\cdot}s^{-1}$) run, completely relaxed (i.e., no anti-G straining maneuver performed), without anti-G suit pressurization until endpoint; 2) a gradual-onset (+0.1 $G_Z{\cdot}s^{-1}$) run, completely relaxed, with anti-G suit pressurization until endpoint; 3) a series of rapid-onset (+6 $G_Z{\cdot}s^{-1}$) runs, completely relaxed, with anti-G suit pressurization until endpoint, beginning at +3.0 G_Z for 15 s and progressing at 1 +G_Z increments with 2 min rest periods between each increment. The highest +G_Z level was duplicated for reproducibility, followed by another +G_Z exposure reduced by +0.5 G_Z to define +G_Z tolerance within ±0.5 G_Z; 4) +5.0 to +9.0 G_Z SACM to fatigue or other endpoint. Endpoints for centrifuge exposures include: 1) medical monitor decision; 2) volitional termination by the subject; 3) nausea; 4) 100% peripheral light loss as determined by the subject; 5) 50% central light loss as determined by the subject; 6) G-LOC (unintentional endpoint). Duplicate centrifuge experimental sessions were conducted for each subject in each anti-G suit. In the event that the maximal SACM duration time between the two rides differed by more than 20%, a third experimental session was completed. This experimental design resulted in 2-3 data collection sessions for the males (one suit) and 4-6 sessions for the females (two suits). Within each suit condition, the replication where the subject performed at the SACM for the greatest duration was used to define the SACM endurance score for data analysis. The dependent variable used for data analysis was maximal +5.0 to +9.0 G_Z SACM endurance (s).

Ergometry/Body Composition Assessment: All exercise testing was conducted according to guidelines and recommendations set forth by the American College of Sports Medicine (2). A motorized treadmill (Quinton Q-65) was used to elicit work for the determination of aerobic capacity from indirect calorimetry (open-circuit spirometry). Expired gas was collected from subjects during tests and analyzed utilizing an automated gas collection/analysis system (Sensormedics 2900z). During testing, subjects also were fitted with a 3-lead electrocardiogram (ECG) configuration for monitoring of heart rate and rhythm using a Quinton Q710 electrocardiograph. The treadmill protocol used was a modification of the Åstrand treadmill protocol (19). Aerobic capacity (VO_{2peak}) was defined as "physiological" [failure of the subject's oxygen consumption to increase with an increase in work demand with confirmation from elevated respiratory exchange ratio (>1.15) and/or heart rate greater than age estimated maximum], "volitional" [subject termination of exercise bout based on self-determined maximal fatigue] or other clinically accepted endpoints as defined elsewhere (2,14). The Wingate Test (4-7) was used to determine peak and mean anaerobic power. Data for the 30-s maximal cycle ergometer test was

gathered using the Cardionics Direct Power Printing Cycle Ergometer and heart rate was monitored using a chest-strap monitor (Polar). Premature termination criteria of the maximal exercise bout are defined elsewhere (2). Body composition was estimated from skinfold measurements (Lange calipers) using the methodology and equations described by Jackson and Pollock (15) for males and Jackson et al. (16) for females. Body mass and stature was measured using a standard balance beam scale with measuring rod (Detecto). Body mass, body stature, percent body fat, fat mass, fat-free mass, mean and peak anaerobic power and aerobic capacity were the variables used for data analysis.

Statistical Analysis: For all dependent variables, an analysis of variance (ANOVA) (1 between-subjects variable, 0 within-subject variables) was utilize to examine differences between genders. With regards the analyses of SACM endurance between genders, in an attempt to account for possible between-subjects variance associated with subject centrifuge experience, the number of +5.0 to +9.0 G_Z SACM exposures each subject had undergone at the time of data collection was utilized as a covariate for the ANOVAs. The alpha level was set at 0.05 for all tests.

COMBAT EDGE Vest and ATAGS Fit Evaluation.

Facilities. All fit evaluations for the CSU-17/P COMBAT EDGE vest and ATAGS were conducted in the Armstrong Laboratory life support equipment development facility, Brooks AFB, TX.

Protocol. Subjects were fitted with a standard USAF flight suit (CWU-27/P), and the following measurements were taken: stature, weight, biacromal breadth, waist height (indent), waist height (omphalion), inseam length, and circumferences at the chest (scye), bust, waist (indent), waist (omphalion), hip, thigh, and calf. Following the standard measurements, the subjects were fitted with the CSU-17/P vest and ATAGS with all lacings adjusted to provide the best fit possible. After garment fitting, the subjects donned a F-16 parachute harness (regular size, PCU-15A/P or small size, PCU-16A/P) and the fit of the vest was evaluated with the subjects seated and the vest pressurized at approximately 25 mmHg (pressure in the vest at approximately +6 G_Z). Data gathered to assess the fit of the garments included measurements at each lacing adjustment (average distance between lacing loops) and an evaluation of specific fit criteria. Fit criteria for the CSU-17/P vest were: 1) Does the suit fit correctly across the shoulders? 2) Can the suit be fitted snugly in the chest area but still allow the subject to take a deep breath? 3) Does the vest bulge excessively across the back when inflated? Fit criteria for the ATAGS were: 1) Does the top of the abdominal bladder overlap the subject's lower ribs? 2) Does the waist of the suit fit snugly? 3) Is the knee of the seated subject at the correct height relative to the knee pocket of the suit? 4) Is the suit the correct length?

Subjects. Ten female subjects, age 19 to 27 years, were used for the fit evaluations. Because these equipment items were not worn as a part of the centrifuge study and involved only anthropometric and equipment fit measurements, the fit evaluation included subjects who were not centrifuge riders. Because the focus of the CSU-17/P pressure vest and the ATAGS evaluation was to evaluate the fit of the equipment on small aircrew, 6 of the female subjects were less than 162.5 cm. in stature. Subject anthropometric data relative to the CSU-17/P (Chest Circumference at the Skye and Bust Circumference) are shown in Table II. Data relative to the ATAGS (Waist Height at the Omphalion and Circumference Omphalion) are shown in Table III. Subject stature and weight are also shown in Table III.

RESULTS

Evaluation of CSU-13B/P fit and male/female acceleration tolerance/endurance comparison. As detailed in Table I, the body mass, body stature, fat-free mass, peak and mean anaerobic power was significantly greater in the male subjects than in the females ($p \leq 0.05$). The males also had significantly ($p \leq 0.05$) lower percent body fat than the females. The genders did not differ significantly ($p > 0.05$) with respect to age, aerobic capacity and fat mass.

With all subjects wearing the OTO suit, the male subjects were able to perform the +5.0 to +9.0 G_Z SACM significantly ($p \leq 0.05$) longer than the females (Figure 2). During the centrifuge exposures in the OTO suits, three of the five female subjects reported terminating their SACM runs due to extreme discomfort related to the anti-G suit.

With subjects wearing their best-fit anti-G suit (males=OTO suit, females=ALMod suit), SACM endurance for females was nearly double their performance in the OTO suit. Additionally, none of the female subjects reported discomfort related to the AL Mod suit during their centrifuge exposures. The SACM endurance difference between the genders was not significantly different ($p>0.05$) (Figure 2).

[Insert Figure 2 Here]

COMBAT EDGE Vest and ATAGS fit evaluation

Table II identifies the critical anthropometric measurements, the percentile rank of the measurements per the 1968 Anthropometry of Air Force Women (9) and the equipment fit relative to criteria for the CSU-17/P pressure vest. The small size CSU-17/P vest provided the best fit for all subjects except subject No. 4 who was best fit with the medium size vest. Per T.O. 14P3-1-161, the small size CSU-17/P vest is designed to fit male aircrew with chest circumferences of 79.4 to 89.5 cm (31.25 - 35.25 in),and the medium vest is sized to male chest circumferences of 89.5 to 99.7 cm (35.25 - 39.25 in). To obtain a best fit, the shoulder lacings of the CSU-17/P were fully taken in for all 10 subjects. All but 2 of the subjects (Subject Numbers 1 and 4) had the chest adjustment lacings maximally taken in and 6 subjects (Subject Numbers 5 6,7,8,9, and 10) had the side lacings fully taken in. The adjustment of the waist lacings varied in accordance to the waist and hip size of the subjects. The fit assessment of the vest, per the CSU-17/P fit criteria, was conducted with the subjects correctly fitted with the torso harness and in a seated position. As shown in Table II, the vest fit was adequate for all but subjects 5 and 6. The vest was slightly large in the shoulder area for these two subjects.

[Insert Table II here]

Anthropometric measurements of stature, weight, waist circumference-omphalion and waist height-omphalion are shown on Table III. Also included in Table III are percentile ranks for stature and weight (1968 Air Force Survey), ATAGS size and equipment fit per criteria for the ATAGS. ATAGS sizes relative to waist circumference-omphalion and waist height-omphalion are shown on Figure 3. The size 1 ATAGS (smallest size currently available) was used for all but two of the subjects (Subjects 2 and 4). Relative to the ATAGS fit criteria, the abdominal bladder height was appropriate for all subjects. In terms of waist fit, the waist circumference was too large for subjects 5 and 6, and subjects 2 and 8 required an alteration (waist tuck) to achieve an adequate fit. The overall length of the suit was too long for the five smaller subjects and the knee fit was incorrect for subjects 5, 6, 8 and 9.

[Insert Table III here]

Figure 3 graphs the subjects' waist height and circumference in relation to the sizing scheme for the ATAGS. The ATAGS is provided in 7 sizes (Size 1,2,4,5,6,8 and 9). The original ATAGS sizing scheme included a size 3 (small, long) and a size 7 (large, short); however a sizing survey conducted by the Armstrong Laboratory, Human Engineering Division indicated that these sizes were not required. A size 0 (extra-small, extra-short) ATAGS was not available for use in the fit evaluation; however, based on design criteria, the size 0 was estimated to accommodate waist heights of 90 to 98 cm and waist circumferences of 64 to 76 cm. Based on these estimates, the size 0 suit would fit all but three of the smallest subjects.

[Insert Figure 3 Here]

DISCUSSION

Evaluation of CSU-13B/P Fit and Male/Female Acceleration Tolerance/Endurance Comparison

In this study, the female subjects, when wearing an anti-G suit properly fitted to their individual anthropometry (i.e., AL Mod suit), were able to maximally endure the +5.0 to +9.0 G_Z SACM to the same degree as the male subjects. In addition, none of the females reported suit discomfort as a reason for terminating their performance of the SACM. This is in stark contrast to the SACM endurance of the female subjects while wearing the OTO suit, which was a misfitted suit for all the female subjects. The males demonstrated significantly greater SACM endurance than that of the females when both genders were wearing the OTO suit, and the majority of the female subjects reported severe suit discomfort as the reason for terminating their centrifuge exposure. As stated previously, Fischer et al., in a retrospective study, cited that males have a greater high-G_Z tolerance than females when both were wearing the OTO suit. Fischer et al. (11) also suggested either greater muscular strength in the males and/or anti-G suit misfit in the females were possible explanations for their findings. The present study provides data which supports the latter hypothesis but offers no support for the former.

The female tolerance to the +5.0 to +9.0 G_Z SACM was certainly enhanced by the appropriately fitted anti-G suit (AL Mod suit). In fact, the +5.0 to +9.0 G_Z SACM endurance times of the females nearly doubled their endurance times when wearing the OTO suit (misfit suit). This, in large part, was because the female subjects, when wearing the AL Mod, were able to perform maximally to the point of muscular/respiratory fatigue. When wearing the OTO suit, the majority of the females were fatiguing prematurely due to severe discomfort related to the anti-G suit and were terminating their centrifuge exposures because of this pain. The resulting increased time to fatigue enabled the female subjects, in the AL Mod suit, to endure the +5.0 to +9.0 G_Z SACM to the same degree as their male counterparts. The male subjects in the present investigation demonstrated significantly greater anaerobic power (both peak and mean) as determined by the Wingate cycle test. The Wingate test does not reveal specific information about muscle strength, per se; rather, the variables measured reflect the explosive characteristics of the subjects' muscle power (peak anaerobic power) and local muscle endurance (mean anaerobic power). It has been suggested that both these variables are limited to some extent by the anaerobic energy pathways (peak anaerobic power=ATP-CP system; mean anaerobic power=anaerobic glycolysis)(7). Such anaerobic performance is highly correlated with the relative content of fast-twitch fibers in the musculature examined which in turn is related to muscular strength (7,10). The female subjects, despite having exhibited significantly lower relative anaerobic power (mean and peak), were able to maximally endure the +5.0 to +9.0 G_Z SACM as long as the males when they were wearing their best-fit anti-G suit. In fact, the female subjects actually performed the SACM longer than the male subjects but, perhaps due to the small female sample size and the resulting lack of statistical power, the endurance time difference between the genders was not statistically significant. These data certainly do not support the idea that increased muscle strength in males could account for increases in +G_Z endurance when compared to females. Further research utilizing more specific muscle strength measurements in conjunction with these gross estimations of anaerobic power will be useful in addressing this topic.

COMBAT EDGE vest and ATAGS fit evaluation

Preliminary fit evaluations of the CSU-17/P pressure vest using small female centrifuge subjects suggested that the vest would be large in the shoulder area and, during inflation tests, the vest was observed to balloon across the back and shoulders. This effect was also observed during a number of centrifuge training sessions in which the COMBAT EDGE system was worn by female trainees. The results shown on Table II indicating that the vest fit was generally adequate for even the smallest subject obviously contradicted the preliminary observation. However, neither the preliminary fit evaluations nor the centrifuge training were conducted with the subjects wearing a torso harness. In the current study, the subjects were fitted with the PCU-15A/P or the PCU-16A/P torso harness. When properly fitted, the torso harness acted as an outer restraint layer for the pressure vest. The ballooning in the back of the vest was eliminated and the shoulder straps of the harness forced the vest to conform to the shoulder contours for all but the smallest subjects. Per TABLE II, the CSU-17/P vest provided an adequate fit in

the chest and back; however, the vest was slightly large in the shoulder area for 3 subjects with chest circumferences (Scye) of 83 cm or smaller. Since the torso harness provides some restraint for the vest in the shoulder area, it is unlikely that the performance of the vest will be degraded even for the smaller individuals. The subjects reported that the vest was comfortable when inflated and they were able to fully inhale and exhale with no chest, breast, back or shoulder discomfort. Based on the current aircrew stature and sitting height requirements, the CSU-17/P pressure vest, when worn under a correctly fitted torso harness, will fit all female aircrew without alteration. Contrary to previous expectations, additional vest sizes and alterations do not appear to be required.

The ATAGS fit evaluation also provided information that contradicted previous assumptions. The suit was expected to fit female subjects better relative to the abdominal bladder height; however, it was also expected that most females would require altered suits to ensure an adequate waist circumference fit. Per Table III, the abdominal bladder height was satisfactory for all subjects including those who did not receive a good fit relative to other criteria. The waist circumference of the size 1 suit was entirely too large for three subjects (Subject No's 5, 6 and 8); however, only 2 (Subject No's 2 and 8) of the other 7 subjects required alterations for waist fit. Both of these subjects were small waisted relative their hip circumferences. The size 1 ATAGS was too long for the shorter subjects, stature ≤155cm. Per Figure 3, the size 0 suit may be expected to fit at least 2 of the smaller subjects indicating that the ATAGS may fit individuals as small as 152.4 cm stature. Using stature as a primary measurement, ATAGS in sizes 0, 1, 2, 4, 5, 6, 8, and 9 may be expected to accommodate over 80% of the Air Force female population (sizes 3 and 7 determined previously to be unnecessary).

SUMMARY

Evaluation of CSU-B/P Fit and Male/Female G-Tolerance/Endurance Comparison. The data presented here certainly support the efficacy of the Armstrong Laboratory modifications to the CSU-13B/P anti-G suit as adopted in T.O. 14P3-6-121, evidenced by greatly improved endurance during the +5.0 to +9.0 G_Z SACM in females (i.e., those most likely to require the modification). Additionally, in the sample examined, the study suggests that, when fitted with a best-fit anti-G suit, female subjects can endure the +5.0 to +9.0 G_Z SACM to the same degree as male subjects. These results are despite the fact that the female subjects examined exhibited significantly lower mean and peak anaerobic power on the Wingate test of muscle power (peak power) and local muscle endurance (mean power).

Citing the difficulty in recruiting subjects in general, and females in particular, for sustained participation in acceleration research of this nature, the authors acknowledge that the small sample size, specifically with regards to the female subjects, is a shortcoming of the present investigation. The particular difficulty experienced with qualification and retention of females deserves additional study on its own merit. The comparison of male/female $+G_Z$ endurance with regards to more specific muscular strength measurement, in conjunction the gross estimations of anaerobic power utilized here, would be useful in addressing the role of muscular strength in $+G_Z$ endurance. Also, the examination of male/female $+G_Z$ endurance utilizing COMBAT EDGE and ATAGS would be of interest and will be conducted in the coming year. We had hoped to complete this study for inclusion in this report, but were unable to recruit and appropriately train sufficient female subjects during this period. Therefore, a report of this study, completion projected for mid-FY98, will be submitted as an addendum to this final report.

COMBAT EDGE and ATAGS fit evaluation. Both the COMBAT EDGE pressure vest (CSU-17/P) and the ATAGS fit a larger portion of the potential female aircrew population than expected. The CSU-17/P vest, when worn under the standard fighter aircraft torso harness, provided a good fit for virtually all subjects. The torso vest tended to act as an outer restraint garment and prevented vest over inflation or ballooning. The vest did not interfere with maximal inspiration or expiration and was reported to be comfortable with no pressure points. In terms of chest circumferences (Skye), the CSU-17/P vest accommodated subjects ranging from 78.7 cm to 101.0 cm . When compared with the population base covered by the 1968 Air Force Survey, the vest, when worn under the torso harness, will fit

approximately 85% of the population. Additionally, no alterations appear to be required for the vest to adequately fit this large segment of the population.

Both the currently used anti-G suit, the CSU-13B/P, and the ATAGS were developed to fit the US Air Force male pilot population. As shown in this paper, the CSU-13B/P can be modified to provide the female with equivalent acceleration protection. It was expected that modifications would also be required for the ATAGS to provide a good fit for females; however, this study found that the ATAGS generally provided a good fit for the female subjects and alterations were only needed for individuals with small waist circumferences relative to the hip circumference. The study also indicated that the size 0 (extra-small, short) ATAGS would fit females with statures as small as 152.4 cm, or approximately 80% of the US Air Force female population.

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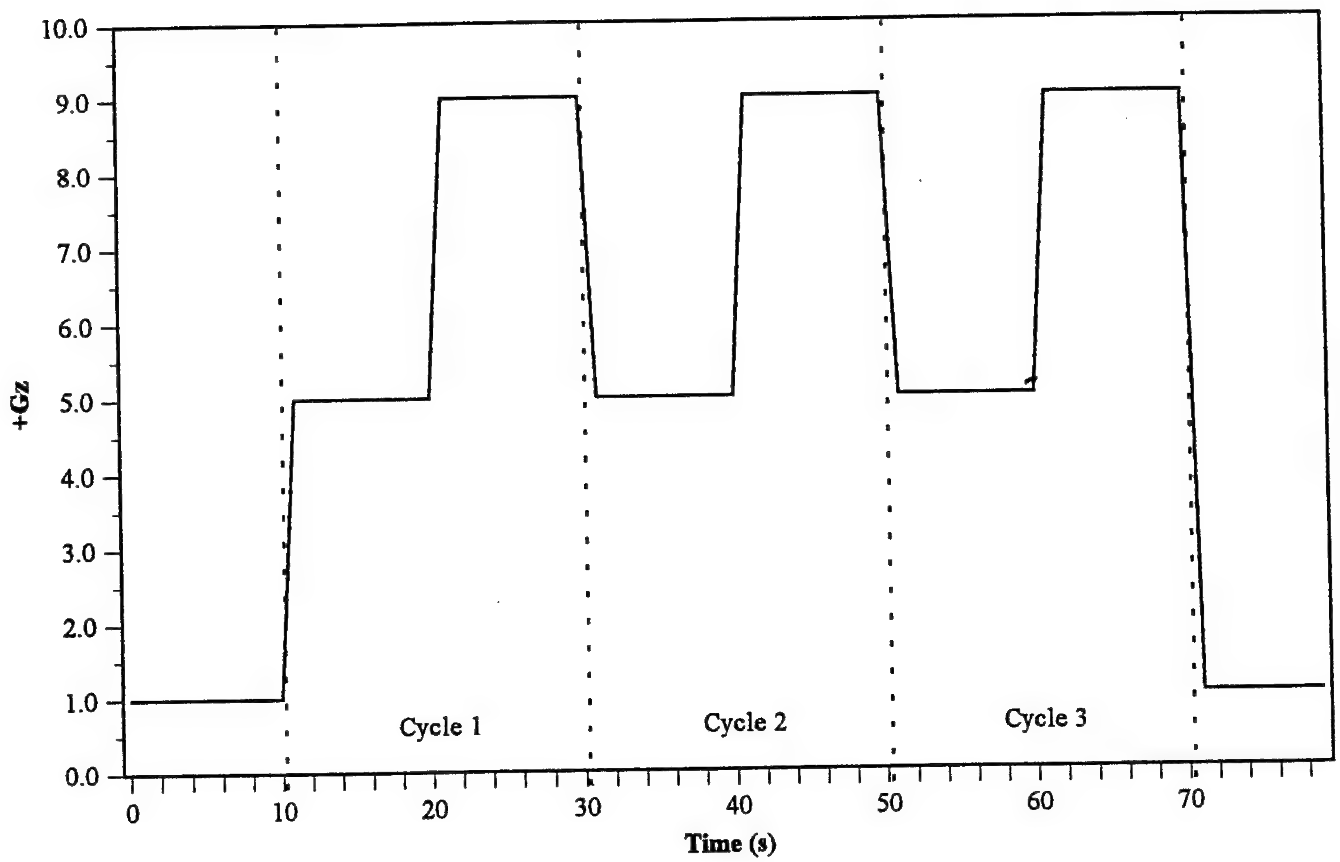

Fig. 1. Depiction of a 3-cycle +5.0 to +9.0 G_z simulated air combat maneuver (SACM).

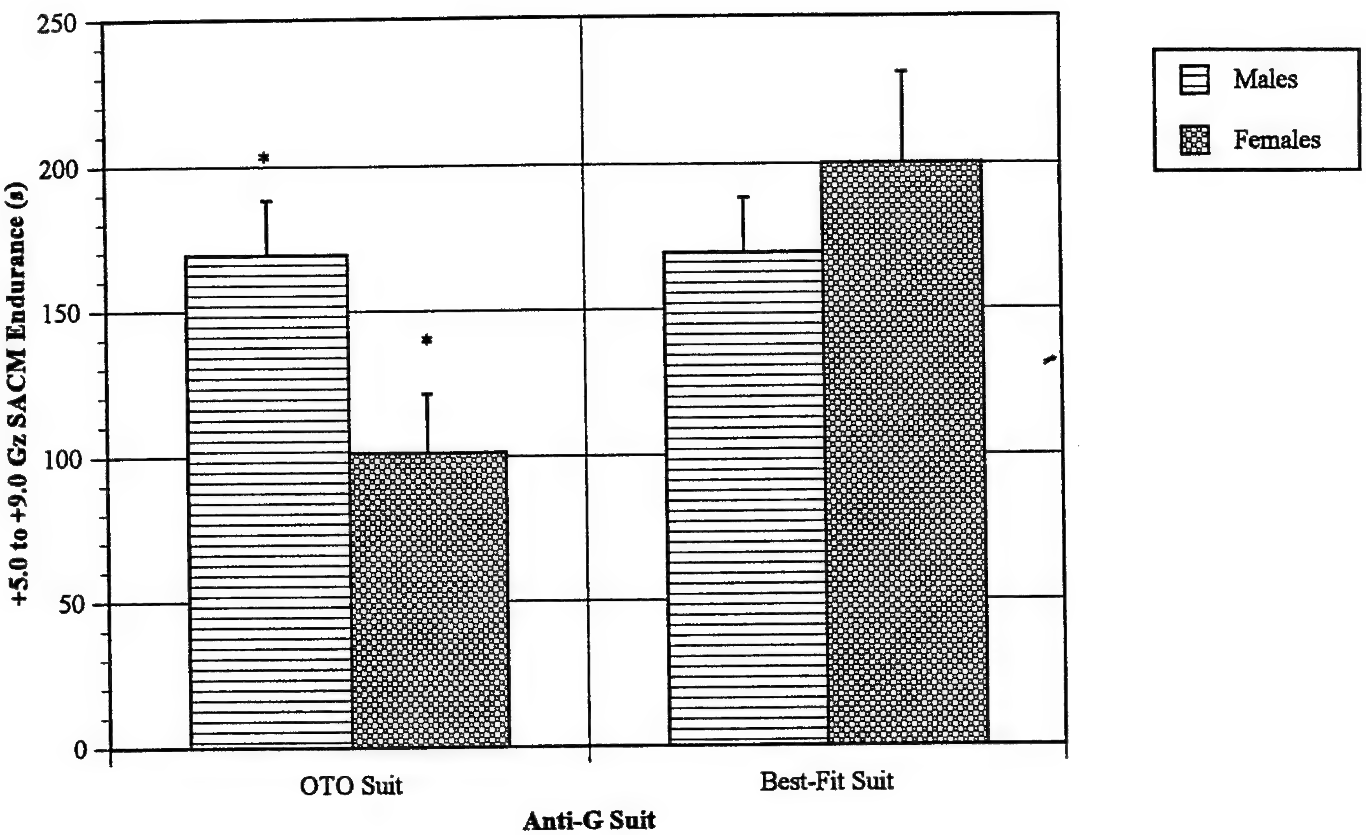

Fig. 2. Male/female +5.0 to +9.0 G_z simulated air combat maneuver (SACM) endurance comparison with subjects wearing the OTO suit and their best-fit suit (males=OTO suit, females=ALMod suit). * denotes significantly ($p \leq 0.05$) different endurance between the genders wearing a specific suit.

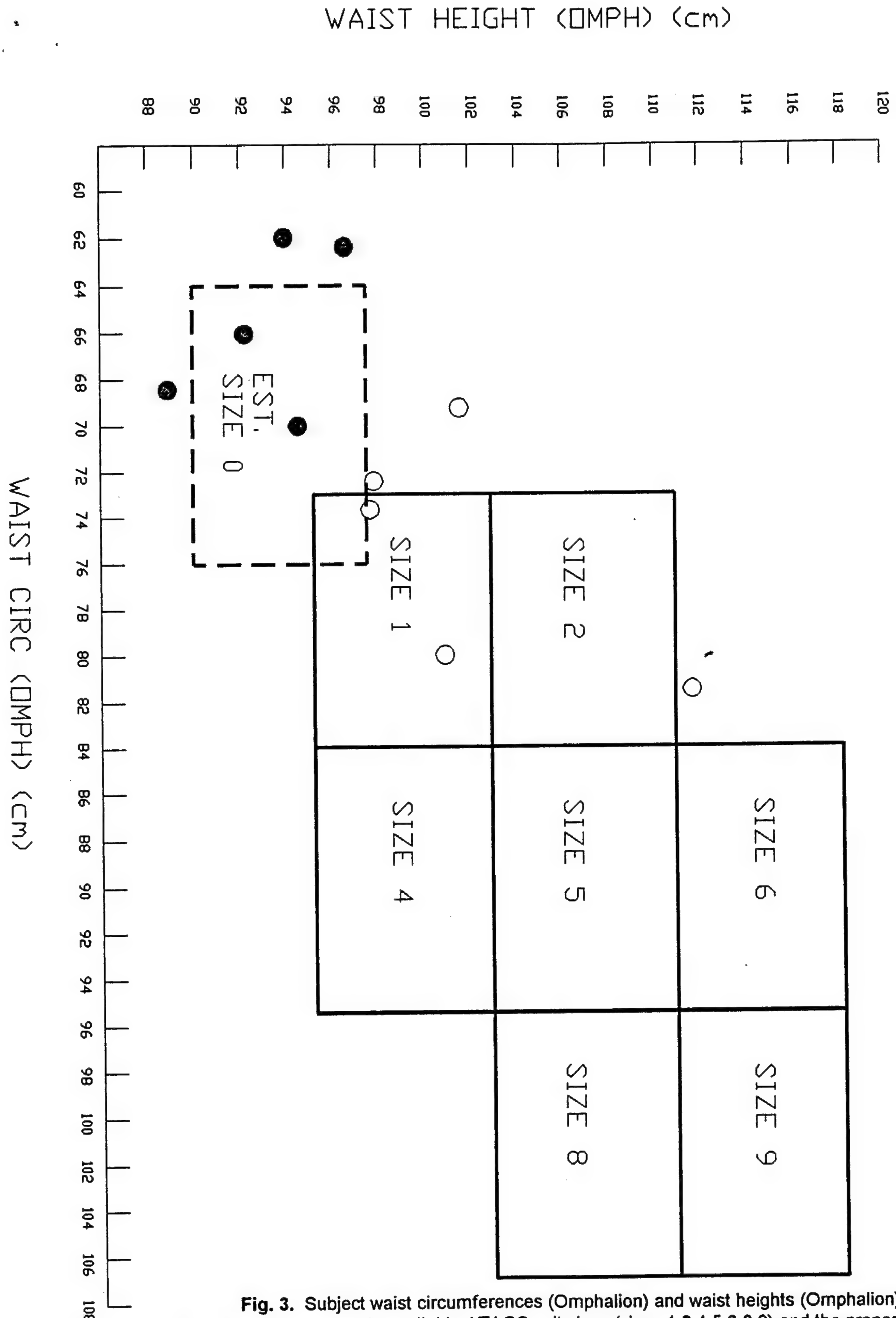

Fig. 3. Subject waist circumferences (Omphalion) and waist heights (Omphalion) shown in relation to the currently available ATAGS suit sizes (sizes 1,2,4,5,6,8,9) and the proposed ATAGS size 0. Open circles (O) indicate subjects fit by currently available ATAGS sizes, including the subjects who required a waist tuck.

TAB LE I. SAMPLE CHARACTERISTICS FOR CSU-13B/P G-SUIT AND MALE/FEMALE TOLERANCE/ENDURANCE COMPARISON

Variable [units]	Males (n=8)	Females (n=5)
Age [yr]	27.5(1.5)	24.6(1.0)
Body Mass [kg]*	78.3(2.1)	66.1(1.9)
Body Stature [cm]*	176.8(1.4)	167.1(2.0)
Body Fat [%]†	14.2(2.3)	26.8(3.9)
Fat Mass [kg]	11.4(2.0)	17.8(2.8)
Fat-free Mass [kg]*	67.0(1.4)	48.4(2.8)
VO_{2peak} [$ml \cdot kg^{-1} \cdot min^{-1}$]‡	45.7(1.7)	41.1(4.0)
Pwr_{mean} [$W \cdot kg^{-1}$]§*	8.3(0.2)	6.7(0.6)
Pwr_{peak} [$W \cdot kg^{-1}$]¶*	11.3(0.3)	8.8(0.4)

Values are means(SE). *denotes significant ($p \leq 0.05$) differences between genders for a given variable; †estimated from anthropometry; ‡VO_{2peak}=peak oxygen consumption from treadmill open-circuit spiromerty; §Pwr_{mean}=mean anaerobic power relative to body mass estimated from Wingate cycle test; ¶Pwr_{peak}=peak anaerobic power relative to body mass estimated from Wingate cycle test.

TABLE II. SUBJECT ANTHROPOMETRY RELATIVE TO THE CSU-17/P PRESSURE VEST AND RESULTS OF FIT EVALUATION

Subject No.	Chest Circ., Skye (cm)	Chest Circ. Percentile	Bust Circ. (cm)	Bust Percentile	Vest Size	Fit Criteria		
						Shoulders	Chest	Back
1	89.0	95	85.1	24	S	Yes	Yes	Yes
2	90.2	90	90.2	64	S	Yes	Yes	Yes
3	83.1	45	85.1	28	S	Yes	Yes	Yes
4	101.0	99	102.2	97	M	Yes	Yes	Yes
5	78,7	14	81.3	7	S	No	Yes	Yes
6	83.0	45	81.0	7	S	No	Yes	Yes
7	82.5	21	83.8	30	S	Yes	Yes	Yes
8	86.4	75	88.9	48	S	Yes	Yes	Yes
9	83.6	48	83.6	15	S	Yes	Yes	Yes
10	85.7	65	86.4	30	S	Yes	Yes	Yes

TABLE III. SUBJECT ANTHROPOMETRY AND RESULTS FROM THE ATAGS FIT EVALUATION

Subject No.	Stature (cm)	Stature Percentile	Weight (Kg)	Weight Percentile	Waist Circ. Omph (cm)	Waist Ht. Omph (cm)	ATAGS Size	Abd. Bladder Ht.	Waist Fit	Knee Ht.	Length
1	163.5	62	58.6	57	80.0	101.0	1	Yes	Yes	Yes	Yes
2	165.1	65	57.7	86	73.7	97.8	4	Yes	Tuck	Yes	Yes
3	165.1	65	57.7	53	69.2	101.6	1	Yes	Yes	Yes	Yes
4	177.8	99	80.0	99	81.2	111.8	5	Yes	Yes	Yes	Yes
5	152.4	6	52.2	24	62.2	94.5	1	Yes	No	No	No
6	152.0	5	46.5	7	61.0	93.0	1	Yes	No	No	No
7	155.0	13	55.7	47	70.0	94.6	1	Yes	Yes	Yes	No
8	152.4	6	48.7	18	66.0	96.3	1	Yes	Tuck	Yes	No
9	149.9	2	52.6	21	68.6	88.9	1	Yes	Yes	Yes	No
10	160.0	38	57.7	52	72.4	97.8	1	Yes	Yes	Yes	Yes

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